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15. Supplementary Notes

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16. Abstract (MAXIMUM 200 WORDS)

Fundamental shortfalls in our understanding of leeway drift behavior have hampered the search and rescue (SAR) planning community's ability to predict search object drift with high confidence. This report organizes the existing body of knowledge on leeway to address many of the shortcomings in the present use of leeway.

Ninety-five leeway target types reported on by twenty-five field studies are presented. The test objects and methods used to measure leeway in these studies are reviewed. The leeway guidance of the present U.S. Coast Guard search planning tools is also reviewed. A comparison between an older leeway data set and a recent leeway data set is used to illustrate recent gains in our understanding of leeway behavior.

A new model is presented for the prediction of leeway drift that takes full advantage of the higher data quality. With search object classes for which high-quality leeway data have been measured, this new model provides substantial reductions in search area size when the new model is compared to leeway predictions made by existing U.S. Coast Guard search planning methods.

A systematic categorization of the possible targets of interest to the Coast Guard is presented as a leeway taxonomy. The leeway taxonomy is based upon rules that describe the target and help quickly guide the search planner through the seven possible levels of the taxonomy.

Sixty-three search object leeway classes and their leeway speed coefficients and divergence angles are recommended for manual search planning tools.

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EXECUTIVE SUMMARY

INTRODUCTION

Leeway is the motion of an object on the surface relative to the local background surface currents. Having an understanding of the leeway of survivors and survivor craft is necessary for prediction of the total drift of those survivors during search and rescue (SAR) cases. In addition to traditional civilian SAR, leeway is critical in combat SAR cases and for the prediction of surface drift objects in Law Enforcement (LE) and Marine Environmental Protection (MEP) missions.

Leeway has been studied since World War II; however, recent studies conducted by the R&D Center and others have provided a number of new and improved leeway data sets and drift models for a variety of SAR craft. Numerous questions regarding this diverse body of leeway data and drift models have been asked within the search planning community. Most of these questions focused on the desire to extract maximum information from available data while providing a cohesive means of presenting the data and modeling leeway drift. This report addresses nine leeway-related questions that: 1.) Organize the existing body of leeway knowledge. 2.) Present a cohesive set of leeway models that make maximum use of available data. 3.) Quantify the impact of leeway model accuracy on the overall SAR mission planning process, particularly with respect to search area size.

QUESTIONS and FINDINGS

1) Which leeway targets have been studied? (For what targets do we have data?)
During 25 field studies 95 leeway target types, including 38 life rafts, 14 small craft (mostly outboards), and 10 fishing vessels, were studied. Other leeway target types studied included surfboards, sailboats, life capsule, Cuban refugee raft, fishing vessel boating debris, and Persons-in-the-Water (PIWs). There have been two significant changes regarding leeway targets since World War II when leeway studies began. First, target descriptions have greatly improved from merely providing the model type of the target to providing line drawings with dimensions. Hopefully, this trend will continue to improve until full 3-D digital images of the targets are available. The second is that SAR targets have themselves been evolving over the years. For example, life rafts have been improved by the addition of full canopies and extensive ballast systems so that they are quite different from the old World War II rubber raft.

2) What methods were used in each leeway field study? (How good is that data?)
Two basic methods of measuring leeway have been used: indirect and direct. The indirect method was used by seventeen studies to generate most of the original guidance for search planning. This method consists of setting out leeway targets near a surface current drifter and measuring the on-scene winds. Then the drift of the surface current drifter is subtracted from the total displacement of the leeway target to estimate the leeway portion of the motion. The accuracy and precision of this method is dependent on the quality of the surface current drifters and the navigation used to position the surface current drifters and leeway targets. The indirect method requires constant maintenance of the leeway targets and drifters as they tend to separate. Thus, this method generally

produced data only in light to moderate winds. The indirect method produced reasonable estimates of the leeway rates of many common SAR targets. However, the results of the indirect method often contained too much noise in the directions of wind and leeway to provide useful guidance on the leeway angle or divergence from the downwind direction.

In the 1990's, the direct method of measuring leeway using internally recording current meters attached to the drifting craft was introduced and calibrated against the indirect method. The new current meters combined with wind monitoring systems, data loggers for GPS positions, and satellite beacons allowed the deployment of leeway targets before a storm and their recovery after the storm, with leeway data recorded throughout. The results were long, continuous records of leeway through the high wind conditions that are of most interest to SAR planning. There have been eight studies performed using the direct method.

3) What is the present level of understanding of leeway behavior?

The following survivor craft leeway behavior has been observed in recent leeway data sets: divergence of the craft from the downwind direction, changes in relative wind direction that lead to changes in sign of the divergence (jibbing), capsizing, and swamping. With larger leeway data sets on a single target type, the difference between positive and negative crosswind components as functions of wind speed is apparent. The downwind component of leeway is higher during rising winds than falling winds for a given wind speed. Observing and quantifying these characteristics of the leeway drift of survivors and survivor craft provides new and clearer understanding of the mechanism of leeway.

4) How can we model the present level of understanding of leeway behavior?

A new model of leeway behavior is introduced that uses linear regression equations and variance of both the downwind and crosswind components of leeway to predict the drift of the targets. This third generation model of leeway drift area is called AP98. AP98 incorporated many features of leeway behavior that have recently been observed, the most significant of which is the inclusion of crosswind components of leeway to express the divergence of the target from the downwind direction.

5) What is present leeway guidance for search planning?

The leeway guidance provided by the National SAR Manual, and the U.S. and Canadian Coast Guard's search planning tools are reviewed in Chapter 5. The guidance provided by these search planning tools is restricted to leeway rate for a limited number of target classes based primarily upon the Chapline (1960) study. Additional guidance for life rafts was added by several studies in the 1970s and 1980s. The very limited guidance on leeway angle or divergence is based upon Hufford and Broida's (1974) report on four small craft (12-21 foot outboards).

6) How does the present leeway guidance compare to the new models of leeway behavior?

A sensitivity study of predicted leeway drift areas showed significant reductions in search area size were achieved by the AP98 leeway model when compared to the first and second generation leeway search area models presently used.

7) What classes of leeway targets should be included in our search planning tools?
A systematic categorization of the possible targets of interest to the Coast Guard is presented as a leeway taxonomy in Chapter 6. The leeway taxonomy is based upon rules that describe the target and help guide the search planner quickly through the seven possible levels of the taxonomy. The taxonomy uses published annual boating guides and references as much as possible to provide the search planner with cross-reference ability. The taxonomy was designed to be easily implemented in numerical search planning tools.

8) Are there new, broader categories of search objects within the leeway taxonomy for which leeway equations can be generated from the available data?
Leeway data from multiple sources were combined together from lower levels in the leeway taxonomy to generate predictions for generalized classes of PIWs, Maritime Life Rafts, Commercial Fishing Vessels, and Medical Waste objects. This analysis is presented in Chapter 7. The combination of deep-ballasted canopied life rafts revealed the importance of the presence or absence of a drogue to the leeway drift of life rafts, and how little effect loading of the raft had on the raft's leeway drift rate. Data combined systematically up the leeway taxonomy table provide leeway drift equations to the search planner as he descends through the leeway taxonomy table from the general to the specific. Thus the SAR planner has leeway guidance for larger, more inclusive categories at the beginning of a SAR case when information about the target type is often incomplete. When further information about the target types has been obtained, more specific leeway guidance will allow for a finer definition of the search area by the SAR planner.

9) What are the recommendations for modeling leeway in search planning tools?
Sixty-three new leeway classes and their values are recommended for inclusion in the next version of the National SAR Manual. These leeway classes are characterized by the leeway taxonomy introduced in Chapter 6 and outlined in Appendix A. The values for the leeway equations are presented in Appendix B. This provides the SAR planner with 63 systematically ordered and fully described leeway categories instead of the present seven poorly defined categories.

10) What is the present level of modeling efforts?
A separate report titled "Modeling of Leeway Drift" by Anderson et al. (1998) addresses this tenth question.

CONCLUSION

This report and Anderson et al. (1998) reflect the status of the field of leeway study and its operational guidance in 1998. There have been significant gains in the understanding of leeway behavior since the field studies of the 1960's and 70's. A newer, more sophisticated model of leeway behavior was therefore developed to accurately reflect the recent advancements achieved in determining the leeway of common SAR targets. It is anticipated that the findings and recommendations of this report will lead to operational guidance that will result in smaller and more accurately defined search areas.